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THE EFFECT OF HUD SYMBOLOGY SIZE ON OPERATOR PERFORMANCE UNDER VARIOUS LUMINANCE CONDITIONS (U)

WILLIAM N. KAMA
GILBERT G. KUPERMAN

ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

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HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



CHARLES BATES, JR.
Director, Human Engineering Division
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19 ABSTRACT (Continue on reverse if necessary and identify by block number) A study was conducted to determine the amount of reduction that could be imposed upon the size of symbology and scales used on the A-10 aircraft head-up-display (HUD). Four symbology and scale sizes were selected for study: (1) the current A-10 HUD display size; (2) a 15% reduction of the current display size; (3) a 30% reduction; and (4) a 45% reduction of the current display size. Twelve subjects "flew" 15 two-minute, air-to-ground missions under three ambient background conditions -- 5 missions at 3000 foot-Lamberts (ft-L); 5 missions at 2000 ft-L; and 5 at 0.001 ft-L. During a given mission, the subject performed an information call out task (primary) and a compensatory tracking task (secondary). Findings from this study indicate that within the range of symbology sizes used, no significant differences in performance were noted. Subjects responded rapidly and accurately, regardless of the symbology size used.					
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PREFACE

This report was prepared by the Crew Systems Effectiveness Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory under Work Unit 71841803, "Transparency Effects on Visual Performance," and in support of Weapon System Project 329A. The authors wish to express their sincere thanks and appreciation to the following personnel who contributed to the successful completion of this study: Messrs Ken Bish, William Foley, John Kettlewell, and Jack Nagel for their outstanding support in assembling the necessary hardware and software programs used in this study; to Sgt Don Smith who aided in the data collection; and to Mr Ron Spicuzza and Ms Freida Thornton for their support in reducing the data.



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SECTION I

Introduction and Background

During test and evaluation flights of the A-10 aircraft, pilots found that (a) excessive head motion (approximately 13 inches in the vertical direction) was required to keep the pipper in view at all times on the head-up display (HUD); and (b) clipping of the display symbology occurred as a result of the pilot's attempt to keep the pipper in view.

To resolve these problems, several solutions were offered. These included (1) shortening of the pilot-to-HUD viewing distance; (2) employing a two-position movable HUD combiner; and (3) reducing the size of the symbology used on the HUD. The first two solutions would be costly, both approaches requiring hardware changes either to the HUD or the cockpit. The third solution affords an approach that can be easily implemented (requiring only a software change) and evaluated. This solution, however, gives rise to the following question: "How much can we reduce the size of the symbology and scales used on the HUD without degrading pilot performance?"

A search of the literature pertaining to HUD research indicates that a great deal of effort has gone into hardware development, but very little has been done with respect to developing design criteria for symbology used on HUDs. For example, Ketchel & Jenny (1968), in surveying the literature dealing with electronically and optically generated aircraft displays, state that "We have found almost no research that pertains to the legibility of HUD alphanumeric symbols." These authors do indicate, however, that symbol sizes of 7 to 10 milliradians (mrad) are commonly found on contemporary HUDs. Kelly, Strudwick, & Ketchel (1965), in an investigation of HUD high brightness requirements, found that a symbol luminance of 1800 to 3500 foot-Lamberts (ft-L) was required for an uncoated combiner viewed against a 10,000 ft-L sky background. Against the same background but using a trichroic coating, the symbol luminance was reduced to 900 to 1000 ft-L.

Although the above references yield information with respect to the size of symbology currently being used on HUDs and the luminance level for such symbology, these references do not provide an answer to the question raised earlier. To obtain an answer to this question, a study was devised to determine the amount of reduction that could be imposed upon the size of symbology and scales used on the A-10 HUD without degrading operator performance.

SECTION II

METHODOLOGY

Experimental Design

A two-factor, repeated measures experimental design (Winer, 1962, p. 302) was used. The two variables of interest were symbology size and ambient illumination. Four levels of symbology size were used. Level 1 represented the current A-10 HUD symbology size; level 2 represented a symbology size 85% that of level 1; level 3, 70%; and level 4, 55% that of level 1.

These four symbology sizes were selected because they cover the range of symbology sizes currently found on contemporary HUDs -- 7 to 10 mrad (Ketchel & Jenny, 1968, p. 153). Level 1 represented the upper limit of this range; level 2, the midpoint; level 3, the lower limit; and level 4, 1.5 mrad below the lower limit.

Since the A-10 is primarily a close air support aircraft, it seemed reasonable that the three levels of ambient illumination to be used in this study should be representative of the environment in which this aircraft would operate. The illumination levels selected represented an earth background on a clear day

(3,000 ft-L); an earth background on a cloudy day (2,000 ft-L), and; a night with a full moon (0.001 ft-L).

Subjects

Twelve male and female subjects were used. Nine were paid volunteers from a local university and three were technicians working for the Air Force. All were right handed and had normal or corrected vision of 20/20. As far as could be ascertained, all subjects were naive with respect to the task employed. The subjects were randomly divided into four groups of three subjects each. Each group differed in terms of the size of symbology which they viewed -- Group I was tested with the current A-10 HUD symbology size; Group II with the symbology size 85% of the A-10; Group III, 70%; and Group IV, 55% of the A-10 symbology size.

Apparatus

A Kaiser HUD with a P-31 (green) phosphor served as the main display upon which was presented the various symbology sizes, mission information, and tracking task. The HUD had an exit aperture of 6 inches. Its total field of view (TFOV) was 20 degrees with the instantaneous field of view (IFOV) being

dependent on the viewing distance and exit aperture size. All symbology and scales, including arrow designators, were generated by a Kaiser programmable electronic symbol generator (PESG). A PDP-11/20 computer was used for the programming and control of the various simulated missions and symbology sizes. It also controlled the input data to the symbol generator. A 1.5-milliwatt helium-neon laser, filtered with a 0.3 Neutral Density filter, was used to generate the cursor for the tracking task. The laser was driven by a pseudo-random number generator and was controlled by the subject through a joystick. Two ColorTran multibeam lights (3200 degrees K color temperature), Model No. 100-31, were used to vary the illumination levels of the background. They were mounted one above the other (8 and 20 inches above the floor) and positioned in-line with the HUD, 18 feet from the background screen. Use of both lights yielded an illumination level of 3,000 ft-L while the top light (used alone) yielded 2,000 ft-L. A 6 x 7 feet, high gain screen provided a homogeneous background against which both the HUD symbology and laser spot (cursor) were viewed. Three recorders -- a stereo tape, a 7-channel magnetic tape, and an 8-channel strip chart -- were used to record subject responses. A Pritchard spectrophotometer, situated directly in back of the subject's station, was used to measure the illumination at the screen to ensure that the desired levels of illumination were obtained. The arrangement and interfacing between each piece of equipment are shown in Figure 1.

Screen

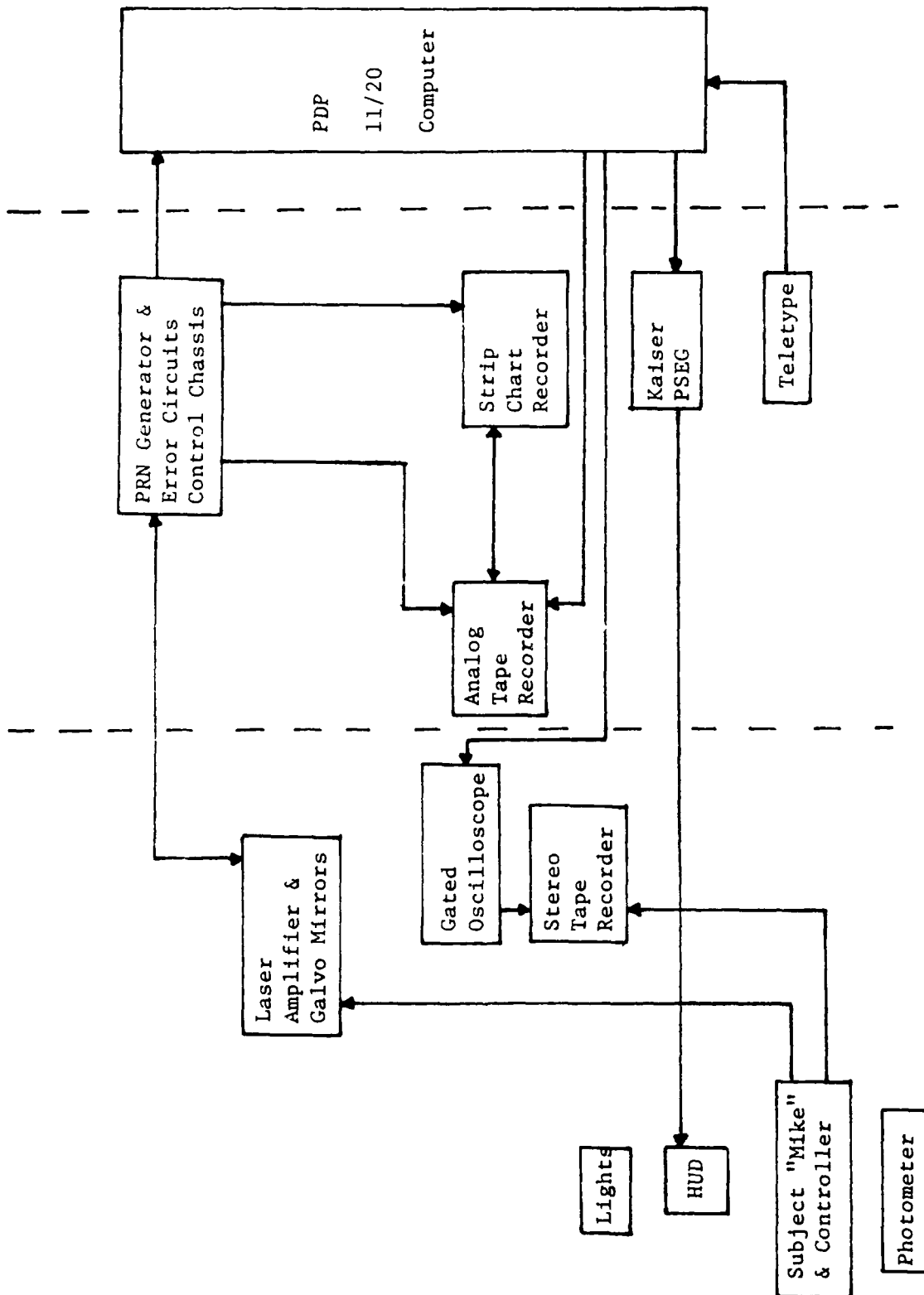


Figure 1. Arrangement and Interfacing of Experimental Equipment.

Task

Twenty, two-minute missions were developed for use in this study. Five were used for training and 15 for data collection. In developing these missions, careful attention was paid to ensure that all parameters (airspeed, altitude and pitch angle) were within the operating capabilities of the A-10 aircraft. Each mission depicted a simulated air-to-ground attack which began at a given altitude, airspeed, and pitch angle. During the mission, all three parameters (altitude, airspeed, and pitch angle) changed continuously. The subject was required to report the value (reading) of one of these parameters at specified points in the mission. The parameter to be reported was designated by the appearance of an arrow designator on the display.

In addition to this information reporting task (primary task), the subject was also required to perform a secondary task. The purpose of the secondary task was to ensure that the subject could not concentrate solely on the primary task, but would have to divide his attention between both tasks. The secondary task was a two-axes compensatory tracking task in which subjects attempted to keep a cursor (laser spot) centered on the pipper located in the center of the aiming reticle. Both of these tasks

(primary and secondary) were considered to be representative of two types of tasks performed by pilots during an air-to-ground attack mission.

Procedure

During the conduct of this experiment, the following procedure was adhered to: All subjects were given two experimental sessions. One was a training session, while the other was the data collection session. During a training session, the subject was seated in front of the HUD and was given a 10 - 15 minute briefing which consisted of a detailed explanation as to the purpose of the study and the task to be performed by him. Particular attention was paid to the primary task. Using a drawing of the display (Figure 2), an explanation of the information depicted was given to the subject. Special attention was given to the airspeed and altitude scales, particularly with respect to the difference in values represented by each scale marking. On the airspeed indicator, the scale markings were equivalent to 5 knots while on the altitude scale, they were equivalent to 100 feet. Subjects were also told that a designator arrow would be used to indicate which of the information sources depicted was to be reported at any given time by them (see Figure 3).

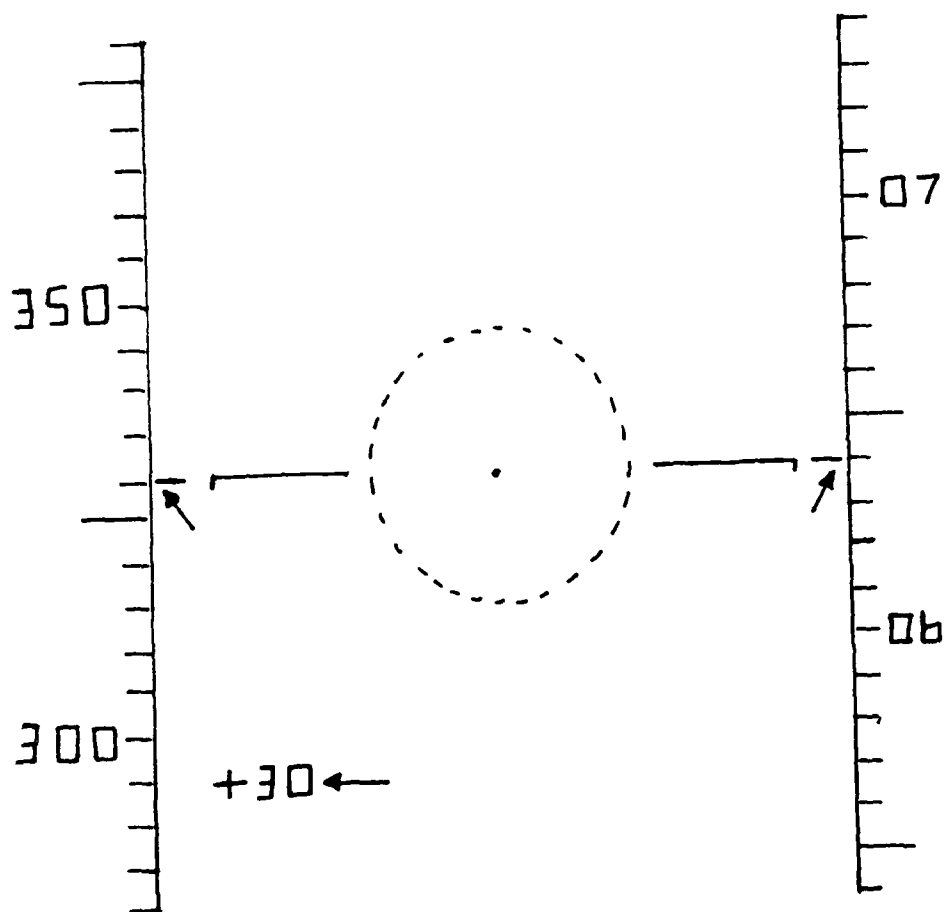


Figure 2. Drawing used to instruct subjects. Airspeed indicator is to left, altitude indicator to right, and Pitch angle at bottom left. Arrows are where they would appear on the display (only one appeared at a time).

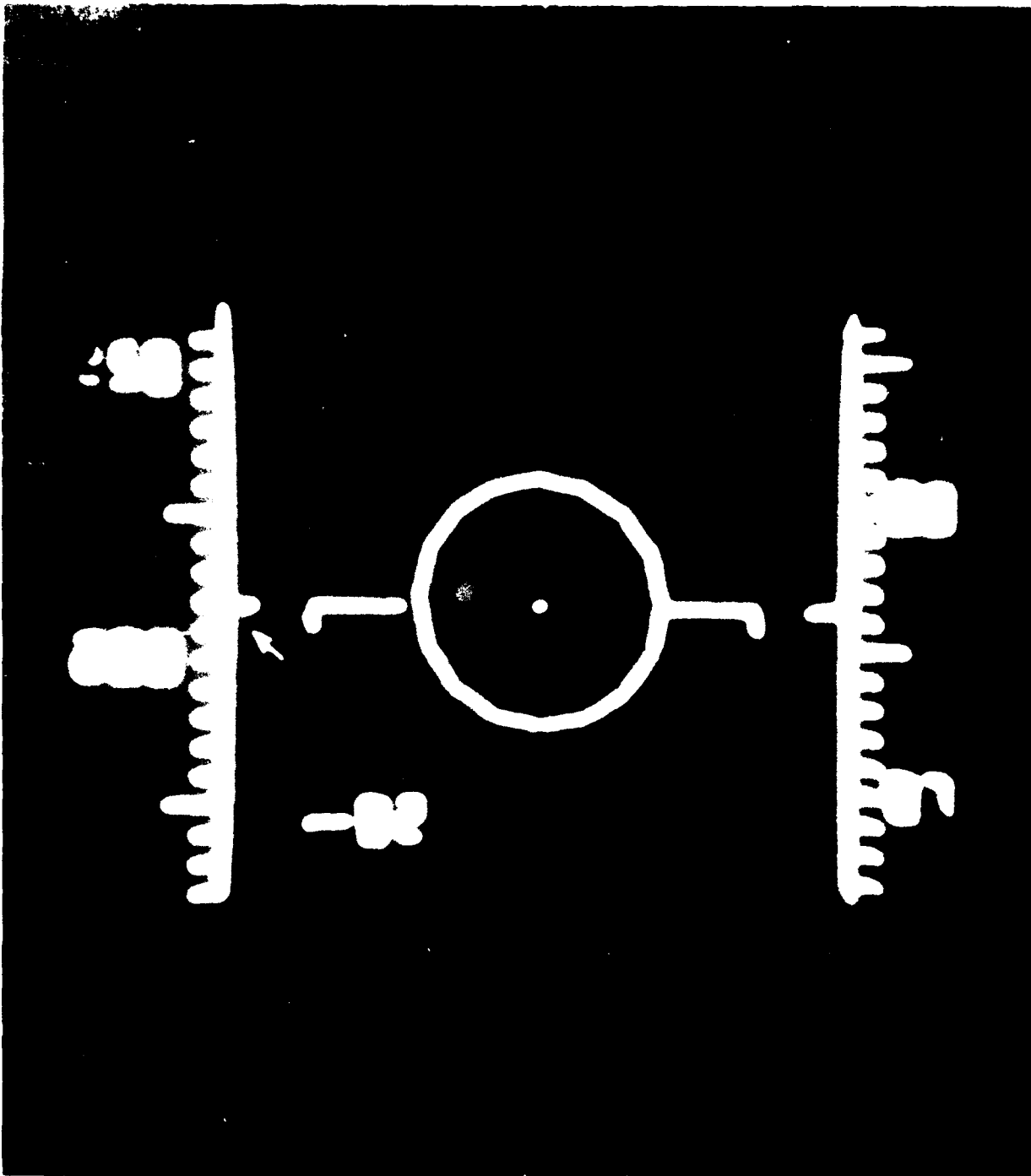


Figure 3. The subject's display showing the laser spot and three information sources -- airspeed (left), altitude (right), and pitch angle (bottom left). Note indicator arrow pointing to airspeed index marker.

Following this briefing, the subject was taken into the testing room and given an opportunity to view an actual mission scenario on the experimenter's monitoring display. The information depicted was again explained to him(her) and he(she) was encouraged to practice calling out some of the readings as each designator arrow appeared on the display. Any questions that the subject had were answered at this time.

After this briefing period, the subject was given 5 two-minute training "flights". During these flights, the experimenter continuously checked to see if the subject encountered any difficulties in going from the airspeed to altitude scale or vice versa. The experimenter also checked to see that the subject was responding correctly, i.e., "minus 2 degrees pitch angle", "250 knots airspeed" or "11,000 feet altitude".

After a short rest period, the subject was instructed on the secondary task. He was then allowed to operate the joystick control and practice tracking for about 5 minutes. He was then given 5 more training flights in which he performed both the primary and secondary tasks. During these training flights, it was emphasized to the subject that his primary concern was the information reporting task but that he was to perform the tracking task as best as he could. All training flights were performed with the current A-10 HUD symbology size under ambient lighting conditions (20 ft-L).

During the data collection phase, subjects were seated 28 inches from the center of the combining glass of the HUD (see Figure 4) and were told to adjust the chin rest located in front of them so that they could see the entire display on the HUD. Placement of the subjects at this distance yielded a field of view equivalent to that found on the A-10 HUD, 9 x 11 degrees. The tracking task was then calibrated by having the subjects indicate to the experimenter when the laser spot was centered over the pipper on the display. After reviewing the tasks to be performed, each subject was given 15 two-minute flights. Five were flown under the 3,000 ft-L condition; 5 under the 2,000 ft-L condition; and 5 under the 0.001 ft-L condition. Five minute rest periods were provided after every fifth flight. The order of exposure for each illumination condition was counterbalanced.

Performance Measures

Measures used to evaluate subject performance were response time and accuracy scores for the primary task and tracking scores for the secondary task. Response time was measured from the time that the designator arrow appeared on the display until the subject responded verbally (stopping a timing device).



Figure 4. Subject's station showing the HUD, tape recorder, chair rest (with attached microphone), and joystick controller.

Accuracy scores were determined by taking the ratio of the total points earned to total points possible and multiplying by 100. The total points possible were 96. Points were awarded on the following basis: For both airspeed and altitude, 4 points were awarded if subjects were within one scale marking of the correct call; 3 points if they were within two scale markings; 1 point if they were within 3 scale markings; and no points if they were 4 markings or more from the correct call. For pitch angle, 4 points were awarded if they were within 2 degrees of the correct call; 3 points if they were within 4 degrees; 1 point if they were within 5 degrees; and no points if they were over 5 degrees from the correct call. Subjects also had to indicate whether the pitch angle was negative or positive to earn the points.

Tracking scores were determined using the following system: A 0.5 volt (1 cm) scoring track was established. The subject was considered to be "on" track as long as he kept the cursor within plus or minus 0.25 volts (0.5 cm) of the center of the track, i.e., zero volts. Whenever he exceeded the limits of the scoring track, he committed a tracking error. The number of errors committed during each two-minute flight was used to evaluate subject performance.

SECTION III

RESULTS

To determine the impact of symbology size and background illumination on subject performance, a conventional statistical analysis (i.e., analysis of variance or ANOVA) was used. The summary tables for the ANOVAs performed on the accuracy scores and response times for the information reporting task are presented in Tables 1 and 3, respectively. Table 1 presents the analysis done on the accuracy scores and indicates that neither symbology size nor background illumination had a significant effect on performance. This finding is reflected in the highly consistent performance attained by all groups across all treatment conditions. Table 2 shows that the largest difference in average performance obtained was 3.2 points. This occurred between the 85% symbology size/2,000 ft-L condition and the 55% symbology size/2,000 ft-L condition.

TABLE 1

Analysis of Variance for Accuracy Scores

=====					
SOURCE OF VARIATION	SS	df	MS	F	p
<hr/>					
Between Subjects	251.90	11			
A (Symbol Size)	21.82	3	7.27	0.25	
Ss within Groups	230.08	8	28.76		
<hr/>					
Within Subjects	95.77	24			
B (Illumination)	0.81	2	0.47	0.09	
B x SswGroup	68.78	16	4.29		
<hr/>					
TOTAL	347.67	35			
=====					

TABLE 2

Mean Accuracy Scores for Each Symbology Size
and Lumination Condition (Points Earned)

	<u>Lumination (ft-L)</u>		
	3,000	2,000	0.001
<u>Symbology Size</u>			
100% (A-10 HUD)	96.2	97.5	96.9
85%	97.5	97.6	94.7
70%	95.3	95.0	95.0
55%	95.0	94.4	96.5

Analysis of the response time data is shown in Table 3. As in the analysis for the accuracy scores, no significant effects due to symbology size or lumination level were obtained. The means obtained for this measure are shown in Table 4 and reflect the overall consistency in performance attained by all groups. The largest difference in mean response time was 0.14 second and

TABLE 3

Analysis of Variance for Response Time

SOURCE OF VARIATION	SS	df	MS	F	p
Between Subjects	0.43	11			
A (Symbol Size)	0.05	3	0.016	0.33	
Ss within Groups	0.38	8	0.048		
Within Subjects	0.10	24			
B (Illumination)	0.02	2	0.010	2.50	
A x B	0.01	6	0.002	0.50	
B x Ss within Groups	0.07	16	0.004		
TOTAL	0.53	35			

occurred when both the A-10 symbology size/0.001 ft-L condition and the 55% symbology size/3,000 ft-L condition were compared with the 70% symbology size/2,000 ft-L condition.

TABLE 4

Mean Response Times for Each Symbology Size
and Lumination Condition (Seconds)

<u>Symbology Size</u>	<u>Lumination (ft-L)</u>		
	3,000	2,000	0.001
A-10	1.31	1.28	1.34
85%	1.21	1.24	1.27
70%	1.24	1.20	1.24
55%	1.34	1.24	1.32

Another means of evaluating the effect of symbology size and background illumination on performance is to examine the number of misses that occurred. The number of misses that occurred under each treatment condition is presented in Table 5. A tabulation of the misses indicate that the largest number (6) occurred with the 55% symbology size at the 3,000 ft-L lumination level. Furthermore, the majority of misses occurred either at the brightest lumination level (3,000 ft-L) irrespective of

TABLE 5

Number of Misses for Each Symbology Size
and Lumination Condition

<u>Symbology Size</u>	<u>Lumination (ft-L)</u>			Total
	3,000	2,000	0.001	
A-10	2	1	0	3
85%	1	0	3	4
70%	2	2	1	5
55%	6	2	3	11
Total	11	5	7	23

symbology size or, with the smallest symbology size (55%), irrespective of the lumination level. In both cases, the total number of misses that occurred was eleven (11).

Tables 6 and 7 present the analyses performed on the tracking scores. Table 6 presents the analysis for the x-axis tracking scores and Table 7 the y-axis scores. Examination of

these two tables indicate that background illumination significantly influenced tracking performance, $p < .05$ ($df = 2, 35$). F-ratios obtained were 4.88 for the x-axis and 4.99 for the y-axis. A Neuman-Keuls test (Winer, 1962, p. 309) on all possible pair of means indicated that for the x-axis, the significance was due to the difference between both the 3,000 ft-L and 2,000 ft-L

TABLE 6

Analysis of Variance for X-axis Tracking Scores

=====					
SOURCE OF VARIATION	SS	df	MS	F	p
<hr/>					
Between Subjects	101.44	11			
A (Symbology Size)	32.36	3	10.78	1.25	
Ss within Groups	69.08	8	8.64		
<hr/>					
Within Subjects	51.04	24			
B (Illumination)	16.12	2	8.06	4.88	.05
A x B	8.48	6	1.41	0.85	
B x Ss within Groups	26.44	16	1.65		
<hr/>					
TOTAL	152.48	35			
=====					

TABLE 7

Analysis of Variance for Y-axis Tracking Scores

=====					
SOURCE OF VARIATION	SS	df	MS	F	p
<hr/>					
Between Subjects	35.95	11			
A (Symbology Size)	8.30	3	2.77	0.80	
Ss within Groups	27.65	8	3.46		
<hr/>					
Within Subjects	68.64	24			
B (Illumination)	18.28	2	9.14	4.99	.05
A x B	21.02	6	3.50	1.91	
B x Ss within Groups	29.34	16	1.83		
<hr/>					
TOTAL	104.59	35			
=====					

illumination levels when compared to the 0.001 ft-L level. For the y-axis, the significance was due to the difference between the 3,000 ft-L and 0.001 ft-L illumination levels. Table 8 presents the tracking performance scores. Symbology size did not influence tracking performance.

TABLE 8

Mean Tracking Score for Each Symbology Size
and Lumination Condition (Error)

		<u>Lumination (ft-L)</u>		
		3,000	2,000	0.001
		<u>Symbology Size</u>		
X-axis	A-10	4.3	4.7	3.7
	85%	2.9	1.5	1.3
	70%	3.4	4.4	2.5
	55%	5.3	4.8	2.5
Y-axis	A-10	4.1	5.6	4.1
	85%	5.1	3.8	2.9
	70%	5.1	2.3	3.1
	55%	4.1	4.4	1.6

SECTION IV

DISCUSSION

The most consistent finding in this study was the lack of influence of symbology size and background illumination upon subject performance for the information reading task. For all measures of performance used, no significant difference in performance was obtained (Tables 1 and 3). This finding is somewhat surprising since it was felt, on an apriori basis, that performance would begin to deteriorate as the amount of reduction increased. Such, however, turned out not to be the case.

One possible explanation for the lack of a significant effect may be attributed to the circumstances of the task used. It will be remembered that the tracking task required the subject to keep a cursor centered on the pipper which was located in the center of the aiming reticle. Since the pipper and the aiming reticle remained stationary and were located in the center of the display, the subject's gaze was essentially fixated to the center of the display. By scanning the display continuously, while still fixating on the tracking task, it was possible for the subject to be aware of each of the values depicted on each of the information channels. Thus, whenever the designator arrow appeared on the display, he was able to respond rapidly and

accurately. The results obtained clearly indicate that this was indeed the case.

Fortunately, in a study such as this one, a lack of significance is just as meaningful as obtaining a significant effect. Recall that the experimental question of interest was to determine the amount of reduction that could be imposed on the size of symbology and scales currently used on the A-10 aircraft HUD. The lack of significance between symbology sizes indicates that the range of reductions used in this study had no effect on operator performance -- all of the subjects responded rapidly (within 1.34 seconds, Table 4) and accurately (94% accuracy or better, Table 2). Thus, reducing the size of the symbology and scales used on HUDs appears to be a viable solution to the clipping problem found on the A-10 HUD.

Based on the range of reductions investigated (15%, 30% and 45%), it is suggested that a limit of 30% reduction be imposed upon the size of symbology and scales used on HUDs. This suggestion is based on an examination of the number of misses that occurred (Table 5) during the study. An examination of Table 5 indicates that almost half of the misses (11 of 23) occurred under the 45% reduction size. Thus, although not readily evident from the results of the analysis (Tables 1 and 3), it would appear that subjects experienced some difficulty with the information reporting task when viewing symbology and scales that

had been reduced by 45%. Further evidence that subjects were indeed encountering difficulty is indicated by the fact that over half of the misses (6 of 11) which occurred under the 3,000 ft-L illumination level occurred with this symbology size. Based on these two findings, selection of the 45% reduction size as a limit appears to be suspect and that selection of the 30% reduction size as a limit would be much more warranted.

Although the tracking scores showed no significant effects due to symbology size (Tables 6 and 7), they did exhibit significance as a result of background illumination ($p < .05$). This significant effect was due primarily to differences in performance which occurred between the 3,000 ft-L condition and both the 2,000 and 0.001 ft-L conditions for the x-axis and between the 3,000 ft-L and 0.001 ft-L conditions for the y-axis.

The above finding is not altogether unexpected. Since subjects had little trouble in reporting the desired information regardless of symbology size, it stood to reason that they would have little difficulty in seeing and performing the required tracking task. However, under the different background illumination levels, some problems were encountered as indicated by the number of misses (11) that occurred under the 3,000 ft-L level. Additionally, on several occasions, subjects commented that they had to work harder to "see" the laser spot and in some instances even indicated that they had "lost it".

SECTION V

SUMMARY AND CONCLUSIONS

This study was conducted to determine the amount of reduction that could be imposed upon the size of symbology and scales used on the A-10 aircraft HUD. Four symbology and scale sizes were selected for study: (1) the current A-10 HUD display size; (2) a 15% reduction of the current A-10 display size; (3) a 30% reduction; and (4) a 45% reduction of the A-10 display size. Twelve subjects "flew" 15 two-minute, air-to-ground missions under three ambient illumination background conditions -- 5 missions at 3,000 ft-L; 5 missions at 2,000 ft-L; and 5 at 0.001 ft-L. During each mission, the subject performed an information call out task (primary) and a compensatory tracking task (secondary). Based on the findings obtained, the following conclusions were drawn:

1. Reducing the symbology size from the current A-10 HUD size to 85%, 70% or 55% of the A-10 display size had no effect on the speed and accuracy with which subjects performed the information call out task.

2. Although the above conclusion indicates that any one of the "reduced" displays appears acceptable, the number of misses which occurred with the 55%-size display makes the selection of this display size unwarranted. It is recommended that the maximum amount of reduction imposed on symbology sizes be limited to 70% or a minimum size of 7 mrad.

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